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Thermal properties of cryo-ground powder of black pepper (Panniyur 1)

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Abstract

The thermal properties of black pepper powder, namely specific heat, thermal conductivity and thermal diffusivity were investigated. The specific heat increased from 225.68 to 4479.53 J kg^{-1} K^{-1} with increase in temperature from -150 to 100°C and moisture content from 3.3% to 18.2% dry basis and it showed a second order polynomial relationship with temperature and moisture content. The thermal conductivity increased non-linearly from 0.1161 to 0.1844 W m^{-1} K^{-1} with increase in moisture content from 3.3% to 18.2% dry basis at 30°C. The thermal diffusivity increased non-linearly from 10.86×10^{-6} to 17.36×10^{-6} m^2 s^{-1} with increase in moisture content from 3.3% to 18.2% dry basis at 30°C. The thermal conductivity and thermal diffusivity showed quadratic relationships with moisture content. The specific heat was affected significantly with moisture content and temperature ($P<0.01$). The thermal conductivity and thermal diffusivity were affected significantly by moisture content.

Keywords: black pepper powder, specific heat, thermal conductivity, thermal diffusivity

Introduction

Black pepper is one of the most important spices and its fruits, known as berries, are dark green in colour which becomes bright orange and red when ripe. After sun drying, its colour changes from grayish to dark brown. It is consumed in the form of whole, cracked, coarse or medium or fine powder and oleoresin.

Generally, mechanical process of grinding is used for size reduction or for producing powder of black pepper. In this process, temperature of the powder rises to as high as 90°C resulting in loss of essential oils, aroma and colour. The quality of the powder can be retained using cryogenic grinding technique (Singh & Goswami 2000). Thermal properties *viz*., specific heat, thermal conductivity and thermal diffusivity are essential for designing a cryogenic grinding system and for simulation and modelling of heat transfer phenomenon in the grinder (Singh & Goswami 2000).

The thermal properties of agricultural materials

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are greatly affected by its temperature and moisture content. In general, specific heat is represented by a function of moisture content using linear relations (Mohsenin 1980). In early work, the effect of temperature on specific heat of agricultural materials was generally not considered (Singh & Goswami 2000). The differential scanning calorimetry (DSC) facilitates the measurement of specific heat as a function of temperature.

Various investigators have studied the thermal properties of agricultural materials using DSC and thermal conductivity meter such as for cumin seed (Singh & Goswami 2000), gram (Dutta *et al.* 1988), borage seeds (Yang *et al.* 2002), minor millet grains (Subramanian & Viswanathan 2003) and guna seed (Aviara *et al.* 2008). The effect of moisture content and temperature on the specific heat of potato using DSC was studied by Wang & Brennan (1993).

The objective of the paper was to study the effect of temperature and moisture content on specific heat, thermal conductivity and diffusivity of cryo-ground black pepper powder. The variations in specific heat with moisture content and temperature and that of thermal conductivity and diffusivity with moisture content at constant temperature of 30^{o} C were investigated.

Materials and methods

Sample preparation

Black pepper (var. Panniyur–1) was procured from Indian Institute of Spices Research, Kozhikode, Kerala (India). The seeds were cleaned manually and broken, foreign matter, split, deformed and immature seeds were discarded before the samples were prepared for the experiment.

The initial moisture content of seed was determined by the vacuum oven method (Ranganna 1986) at a temperature of 80^{o} C and pressure of 100 mm Hg until a constant weight was obtained. The initial moisture content of the black pepper was found to be 10.4% dry basis. Initially, the seeds were stored at room temperature (25^{o}C) for 2 to 3 weeks. For experimentation, a predetermined quantity of black pepper powder, was dried in tray dryer at 50^{o}C to achieve the desired low moisture content. To achieve high moisture contents, calculated amount of water was added and mixed thoroughly to ensure uniform moisture distribution. The samples were packed in low density polyethylene (LDPE) pouches and kept at 5^{o}C for 48 h in refrigerator for uniform distribution of moisture throughout the seed. For measurement of the thermal properties, the pouches were taken out from the refrigerator and allowed to warm to room temperature for 2 to 3 h. Five levels of moisture content (3.3%, 6.7%, 10.3%, 13.8% and 18.2% dry basis) were selected in this study. Experiments were conducted in Thermal and Physical Properties Laboratory at IIT, Kharagpur, India.

Experimentation and observation

The black pepper was ground in the grinder (Model Pulverisette 14, Fritsch Industries, Germany) using liquid nitrogen (LN_2) so that properties of black pepper powder do not vary significantly. The ground black pepper samples thus obtained were used for determination of thermal properties of black pepper.

Specific heat of the black pepper samples was determined by using Differential Scanning Calorimetry (Netzsch DSC 204 'Phoenix', Germany). Before conducting the experiments, the DSC was calibrated for temperature range from -150% to 350°C. For determination of specific heat, the black pepper samples were kept in an aluminium crucible in small quantity (between 12.300 to 14.700 mg) at all five moisture levels. The aluminium crucible was closed and run in the DSC for the temperature range of -150% to 350°C. In this experiment, thermograms were obtained and the variation of specific heat with temperature were determined by the method reported by Singh & Goswami (2000, 2006) for each moisture content. Considering that most of the spice grinding (cryogenic as well as conventional) takes place between temperature ranges of -150% to 100°C, the data was taken between -150% to 100°C for analysis.

A quick thermal conductivity meter (Model: Kemtherm QTM-D3, Kyoto Electronics

Manufacturing Co. ltd, Tokyo, Japan) was used for determination of thermal conductivity of the black pepper samples. The thermal conductivity meter was calibrated using standard reference plate. After calibration, a sample pan of volume 100 cm^3 was filled with black pepper samples for determination of thermal conductivity. The weight of black pepper sample in pan of volume 100 cm^3 was also measured to calculate the bulk density of the samples. The experiments were conducted in triplicate at five moisture levels at average sample temperature of 30°C in the thermal conductivity meter and the mean values were taken in the study.

The bulk thermal diffusivity of black pepper samples was calculated from experimentally obtained values of specific heat, bulk thermal conductivity and bulk density at 30°C using Eq. (1) (Singh & Goswami 2000):

$$\alpha_b = k_b / \rho C_p \qquad (1)$$

where α_b is the bulk thermal diffusivity ($m^2\ s^{-1}$), k_b the bulk thermal conductivity ($W\ m^{-1}\ K^{-1}$), C_p the specific heat ($J\ kg^{-1}\ K^{-1}$) and ρ is the bulk density ($kg\ m^{-3}$).

Statistical analysis

The data obtained were analysed using Statistica 6.0 and Microsoft Excel 2003 for obtaining the variation in specific heat with temperature and moisture content. Analysis of variance (ANOVA) was also performed for statistical analysis of the thermal properties (Table 1).

Results and discussion

Specific heat (C_p)

The specific heat of black pepper sample increased with increase in moisture content (Fig. 1). A similar trend was reported in the specific heat of guna seed (Aviara *et al.* 2008), cumin seed (Singh & Goswami 2000), soybean (Aviara *et al*. 2003; Deshpande & Bal 1999; Deshpande *et al.* 1996), sheanut kernel (Aviara & Haque 2001), and borage seed (Yang *et al*. 2002). The results indicated that the specific heat was affected significantly by moisture content and temperature.

The specific heat increased from 225.68 to 4479.53 J kg^{-1} K^{-1} with the increase in moisture content (M) from 3.3% to 18.2% dry basis and

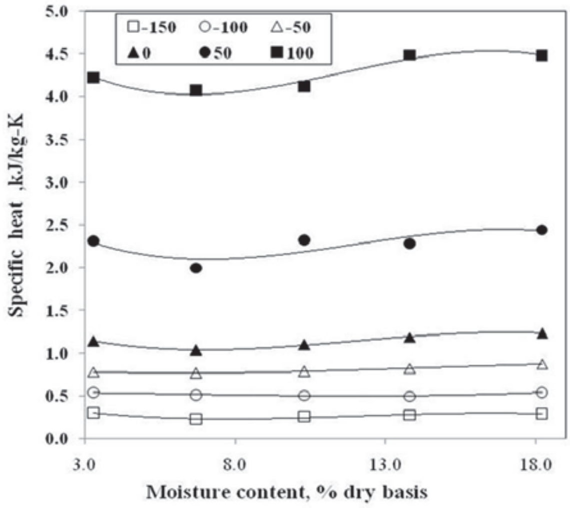

Fig. 1. Influence of moisture content on specific heat of ground black pepper powder

Table 1. ANOVA for specific heat, thermal conductivity and thermal diffusivity of cryo-ground black pepper powder

Source	d.f.	Mean Square	F Value	P Value
Specific heat				
Moisture content	1	35177986	35.7*	1.49E-07
Temperature	1	36824921	37.2*	9.23E-08
Thermal conductivity				
Moisture content	1	265.24	15.6*	0.004214
Thermal diffusivity				
Moisture content	1	272.38	16.1*	0.003914

*Significant at P<0.01; F tabulated values at the degree of freedom 1, 58 is 7.09 and 1, 46 is 7.22

temperature (T) from -150°C to 100°C (Figs. 1 & 2).

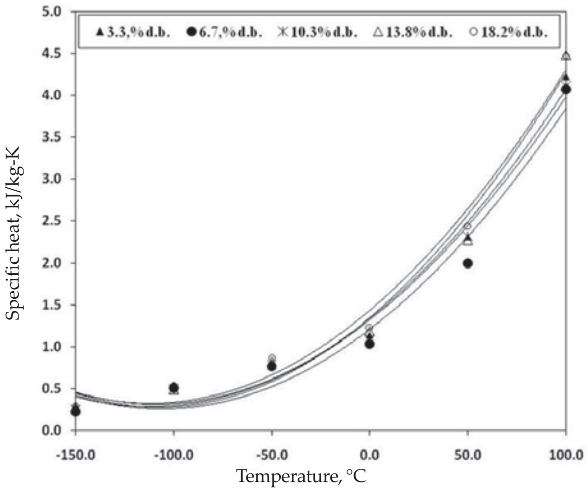

Fig. 2. Influence of temperature on specific heat of ground black pepper powder

The relationships of specific heat with temperature and moisture content have been presented in Tables 2 and 3.

Thermal conductivity (k)

The thermal conductivity of black pepper sample at an average temperature of 30°C is presented in Fig. 3. From the figure, it is clear

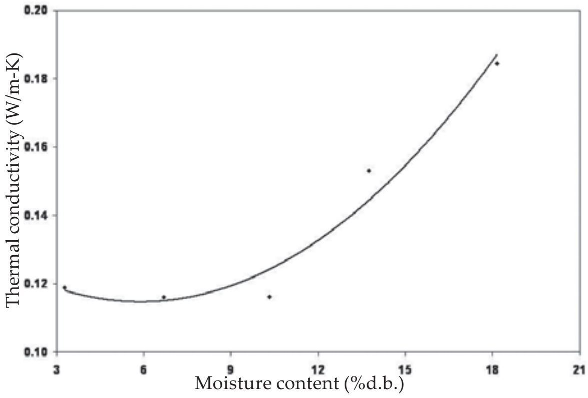

Fig. 3. Variation in thermal conductivity of black pepper powder due to moisture content at 30°C

that the thermal conductivity increased with increase in moisture content. Similar trend was reported for the thermal conductivity of guna seed (Aviara *et al.* 2008), cumin seed (Singh & Goswami 2000), soybean (Deshpande *et al.* 1996), sheanut kernel (Aviara & Haque 2001), borage seed (Yang *et al.* 2002), rough rice (Yang *et al.* 2003), and millet grains (Subramanian & Viswanathan 2003). It was observed that the thermal conductivity of black pepper samples at an average temperature of 30°C increased from 0.1161 to 0.1844 W m^{-1} K^{-1} with increase

Table 2. Second order regression equations for specific heat of black pepper sample vis-à-vis moisture content and temperature

Details of parameter		Second order regression equation	R^2
	3.3	C_p = 9E-05T^2 + 0.018T + 1.332	0.982
Moisture content	6.7	C_p = 8E-05T^2 + 0.017T + 1.211	0.966
(% d.b.)	10.3	C_p = 8E-05T^2 + 0.018T + 1.319	0.983
	13.8	C_p = 9E-05T^2 + 0.019t + 1.350	0.976
	18.2	C_p = 9E-05t^2 + 0.019T + 1.433	0.981

Table 3. Third order regression equations for specific heat of black pepper sample vis- à-vis temperature and moisture content

Details of parameter		Third order regression equation	R^2
	-150	C_p = -0.000M^3 + 0.006M^2 - 0.068M + 0.454	0.936
	-100	C_p = 5E-05M^3 - 0.000M^2 - 0.002M + 0.545	0.946
Temperature	-50	C_p = -6E-05M^3 + 0.002M^2 - 0.025M + 0.836	1.000
(ºC)	0	C_p = -0.000M^3 + 0.014M^2 - 0.142M + 1.464	0.997
	50	C_p = -0.000M^3 + 0.026M^2 - 0.266M + 2.898	0.665
	100	C_p = -0.001M^3 + 0.036M^2 - 0.343M + 5.005	0.938

in moisture content from 3.3% to 18.2%. The relationship between thermal conductivity and moisture content can be expressed by Eq. (2):

$$k_b = 0.0005M^2 - 0.0056M + 0.1314 \ (r^2 = 0.96) \quad (2)$$

for 3.3% dry basis $\leq M \leq$ 18.2% dry basis

Similar results were reported by Chandra & Muir (1971) for wheat and Singh & Goswami (2000) for cumin seed. They reported that the thermal conductivity increased as a non-linear function of moisture content. It was observed that thermal conductivity was affected significantly by moisture content (Table 1).

Thermal diffusivity (α)

The thermal diffusivity of black pepper samples at 30°C was calculated using Eq. (1) and its variation with moisture content is shown in Fig. 4. The thermal diffusivity increased non-linearly from 10.86×10^{-6} to 17.36×10^{-6} m^2 s^{-1} with increase in moisture content from 3.3% to 18.2% dry basis at 30°C. The relationship between thermal diffusivity with moisture content can be represented by Eq. (3):

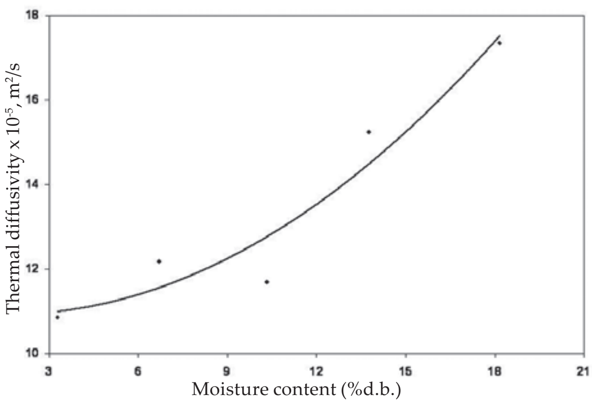

Fig. 4. Variation in thermal diffusivity of black pepper powder due to moisture content at 30°C

$$\alpha_b = 0.024M^2 - 0.0748M + 10.985 \ (r^2 = 0.93) \quad (3)$$

for 3.3% dry basis $\leq M \leq$ 18.2% dry basis

From Table 1, it is clear that thermal diffusivity was affected significantly by moisture content.

Both positive and negative relationship between thermal diffusivity (α) and moisture content (M) have been reported (Dutta *et al.* 1988); Jiang *et al.* 1986; Yang *et al.* 2002; Singh & Goswami 2000). From Eq. (1), it is clear that the magnitude of α depends on the combined effect of k, p(rho) and C_p. For the material where the value for k increases faster than that for p(rho) and C_p in the same temperature and moisture ranges, such as gram, thermal diffusivity would increase with increase in moisture content (Dutta *et al.* 1988; Yang *et al.* 2002).

From this study, it was observed that specific heat of black pepper samples increased from 225.68 to 4479.53 J kg^{-1} K^{-1} with the increase in moisture content from 3.3% to 18.2% and temperature from -150°C to 100°C. It was affected significantly ($p \leq 0.01$) by moisture content and temperature. The thermal conductivity of black pepper powder increased from 0.1161 to 0.1844 W m^{-1} K^{-1} with the increase in moisture content from 3.3% to 18.2% at 30°C. Its variation showed a quadratic relationship with moisture content and it was affected significantly by moisture content. The thermal diffusivity of black pepper powder increased from 10.86×10^{-6} to 17.36×10^{-6} m^2 s^{-1} at 30°C with the increase of moisture content from 3.3% to 18.2%. It was affected significantly by moisture content and its variation showed a quadratic relationship with moisture content.

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